Fermilab Directorate

MEMORANDUM OF UNDERSTANDING FOR THE 2007-2009 TEST BEAM PROGRAM

T969

GammeV

A gamma to milli-eV particle search

April 10, 2007

INTRODUCTION

This is a Memorandum of Understanding (MOU) between the Fermi National Accelerator Laboratory and experimenters of the **G**amme**V** experiment who have committed to participate in this test experiment to be carried out during the 2007 laboratory program.

This memorandum is intended solely for the purpose of providing a work allocation for Fermi National Accelerator Laboratory and possible participating universities and institutions. It reflects an arrangement that is currently satisfactory to the parties involved. It is recognized, however, that changing circumstances of the evolving research program may necessitate revisions. The parties agree to negotiate amendments to this memorandum to reflect such revisions.

The **G**amme**V** experiment is a gamma to milli-eV particle search using a "light shining through a brick wall" technique.

MOTIVATION

The milli-eV mass scale may be relevant to the energy frontier, neutrino properties, and astroparticle mysteries such as dark matter and dark energy. In the energy frontier, a see-saw mechanism between the electroweak symmetry scale and the Planck scale could give rise to phenomenon at the $M^2_{EW} / M_{PL} \sim 1$ meV scale. Neutrino mass differences are measured in units of meV. Possible candidates for dark matter such as a gravitinos or axions may exist at the meV scale. Finally, it is noted that vacuum energy density described by dark energy is $\Lambda^4 \sim 7 \times 10^{-30}$ g/cm^3 ~ (2 meV)^4. The **G**amme**V** experiment seeks to detect oscillations between gamma's and meV mass scale particles to begin study in this interesting region.

Recently, the PVLAS collaboration has reported measurements of anomalous vacuum magnetic dichroism or polarization rotation [PRL 96, 110406 (2006)] and birefringence or polarization ellipticity generation [ICHEP06] which, when interpreted as a new two-photon interaction, imply new resonances of the vacuum at the milli-eV scale with a coupling constant between 10^{-6} and 10^{-5} GeV^{-1} (interpretations such a milli-charged fermions also appear in the theoretical literature). The PVLAS measurement itself and the interpretation have received some criticism. The meV scale particle would be an axion-like particle (ALP) with a much stronger coupling than expected for the QCD axion. In addition, limits set by the CAST experiment at CERN, which seeks to detect ALPs produced in the sun, are in contradiction with this interpretation of the PVLAS signal. However, there are theoretical models which evade these limits and would remove the contradiction. The prospect that the PVLAS signals could be a first indication of a beyond the Standard Model particle has resulted in a number of proposals at various laboratories world-wide to check the interpretation. The **G**amme**V** experiment can test the PVLAS region of interest in an efficient manner with the potential of being the first experimental test world-wide of the expected photon regeneration process assuming the new milli-eV particle interpretation.

The ALP interpretation of the PVLAS data can be tested in a "light shining through a brick wall" experiment where a photon in a high magnetic field can convert into an ALP, travel through the "brick wall," and then reconvert back into a photon. Such an experiment has previously been

performed by the BFRT collaboration [Z Phys. C, 56, 505 (1992)] in the early 1990s. The probability for a photon to be regenerated depends on the length of the traversal in the magnetic field and BFRT happened to use a magnet which gave a result with minimal sensitivity in the meV mass range exactly where the PVLAS signal would suggest a new resonance may occur.

PROJECT DESCRIPTION

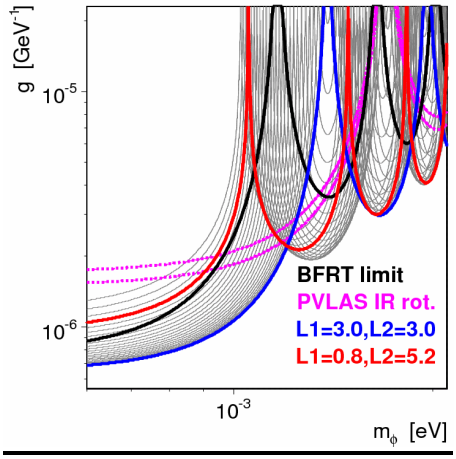
The experimenters will perform a "light shining through a brick wall" experiment that has sensitivity in the PVLAS region of interest. This sensitivity happens quite naturally using a 6m long Tevatron dipole magnet with a 5T field in which sits a beam absorber or "brick wall", an existing pulsed Nd:YAG laser, and a single photon counting PMT. The experiment is unique in the way that the "brick wall" is moved to different discrete positions in order to span the mass range with maximal sensitivity. The experiment is also unique in that it is of smaller scale than other proposals, costs less, and should produce results more quickly than the competing experiments. Similar to neutrino oscillations, the conversion and reconversion probabilities oscillate with the magnetic baselines, L_i, before and after the "brick wall" and the total probability is given by:

$$P_{regen} = \frac{16 B_1^2 B_2^2 \omega^4}{M^4 m_\phi^8} \sin^2\left(\frac{m_\phi^2 L_1}{4\omega}\right) \cdot \sin^2\left(\frac{m_\phi^2 L_2}{4\omega}\right)$$

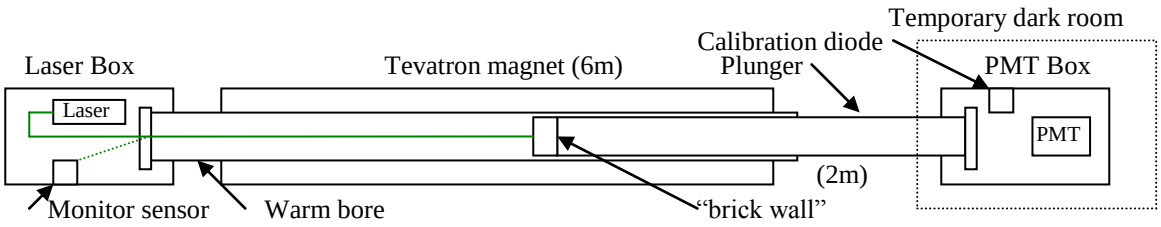
Using a 5T Tevatron magnet and an existing frequency-doubled Nd:YAG laser which produces 160 mJ, 5ns pulses of 532nm light at a frequency of 20 Hz, and assuming the central values for the mass and coupling given by PVLAS, the regeneration probability is given by:

$$P_{regen}^{GammeV} = (3.8 \times 10^{-21}) \times \frac{(B_1/5\text{ T})^2 (B_2/5\text{ T})^2 (\omega/2.33\text{ eV})^4}{(M/4\times 10^5\text{ GeV})^4 (m_\phi/1.2\times 10^{-3}\text{ eV})^8}$$
$$\times \sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times 10^{-3}\text{ eV})^2 (L_1/2.5\text{ m})}{(\omega/2.33\text{ eV})}\right) \sin^2\left(\frac{\pi}{2}\frac{(m_\phi/1.2\times 10^{-3}\text{ eV})^2 (L_2/2.5\text{ m})}{(\omega/2.33\text{ eV})}\right)$$

With the "brick wall" in the center of a 6m long magnet, $L_1 = L_2 = 3$m, the signal rate including detector efficiency would be 5 x 10^{-3} Hz. Using a low noise (100Hz) PMT that has a 5ns pulse window, the noise rate (coincidence with the 20Hz laser pulse) is given by R_{Noise} ~ (20 Hz) (5 ns) (100 Hz) ~ 1 x 10^{-5} Hz. The 95% CL limits that can be set with 5 hrs of running at a variety of "brick wall" positions are calculated. The L1=L2=3m and L1=0.8, L2=5.2m configurations cover the (purple) PVLAS region of interest and fill in the BFRT region of minimal sensitivity (black).



The figure below shows the schematic of the experiment.



PERSONNEL AND INSTITUTIONS:

Scientific co-spokespersons: A. Chou, Fermilab
W. Wester, Fermilab

The group members at present are (all Fermilab):

1.1 A. Chou, W. Wester, A. Baumbaugh, P. Mazur, J. Steffen, R. Tomlin, Xi Yang, J. Yoo

Other commitments:
Pierre Auger: A. Chou, P. Mazur
CDMS : J. Yoo
CDF, DES, SNAP: W. Wester
PPD Electrical Engineering: A. Baumbaugh
Acc Div.: R. Tomlin, Xi Yang

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS

2.1 LOCATION

2.1.1 The **G**amme**V** experiment will be conducted at the Magnet Test Facility (MTF) located in Industrial Building 1 (IB1) at Fermilab. Test Stand 6 in MFT will be used to support the magnet. The laser box will be supported near the feed can which services the magnet for cryogenic operation. A 36 in. x 36 in. optical bench that is incorporated into the laser box will be supported on a large cement block on the floor of MTF or in a similar way in a manner that allows for access to nearby existing equipment. The PMT box will be supported approximately 2-3 meters beyond the cryogenic return can on the stand that is sometimes used to support a second magnet. A small area adjacent to the PMT box will be used for the computer and DAQ system. This location is operated by the Technical Division.

2.1.2 The mechanical construction of the Laser and PMT boxes and the plunger will take place at Lab 8 facility in the Fermilab Village, which is operated by the Particle Physics Division.

2.1.3 The optical prototype will be assembled and operated in the Linac Laser lab in the Linac building. This room is configured with an interlock as a safety measure for the operation of a Class IV laser. This area is operated by the Accelerator Division.

2.1.4 The data acquisition electronics and software will be assembled on the 14th floor of Wilson Hall at Fermilab in space used by the electrical engineering department of the Particle Physics Division.

2.1.5 Various other areas are expected for short term tests such as the laboratory space in the cross connect at SiDet operated by the Particle Physics Division, which has various test stand dark boxes that can be used for bench testing of the photomultiplier tube.

2.2 BEAMS (LASER only)

2.2.1 The **G**amme**V** experiment will use a photon beam generated by a Class-IV Nd:YAG laser at 1064nm capable of 420mJ pulses at 20Hz. When the light is frequency doubled to 532nm, the energy per pulse is 160mJ which is approximately 4.3×10^{17} photons per pulse or an average power of approximately 3.2W.

2.3 SETUP

2.3.1 The **G**amme**V** experiment and support systems will be installed and operated at the MTF in Industrial Building 1.

2.3.2 Crane operators will be needed to mount the chosen Tevatron dipole magnet on Test Stand No 6 – this is part of normal operations in the facility and a candidate magnet, TC1206, currently is mounted. The experimenters also anticipate the need to move a large cement block or other structure to be used for supporting the laser box near the feed can.

2.3.3 Additional equipment including the laser box, PMT box, and plunger can be transported on a cart. PPD technical personnel will be responsible for the setup of these items with minimal consultation with MFT technical personnel.

2.3.4 A small number of cables will interface various components of the experiment to the data acquisition system. No extra-ordinary cabling effort is required.

2.4 SCHEDULE

2.4.1 The set-up of the experiment will occur during the month of May 2007. This will involve the movement of most of the materials (laser box, PMT box, and plunger) from Lab 8 and into the magnet test facility.

2.4.2 The first half of June 2007 will involve the integration of the equipment onto the Test Stand including various alignment and laser tests and measurements. The end step of this activity will be the installation of the photomultiplier tube.

2.4.3 Data taking will begin in the second half of June 2007.

2.4.4 Additional data taking may be required in July 2007 in order to verify initial results of the experiment. In addition, since **G**amme**V** will have to operate with minimal disturbance to LARP testing and the vertical test stand commissioning, the data taking running period may be adjusted from this schedule.

III. RESPONSIBILITIES BY INSTITUTION - NON FERMILAB

Placeholder. The experiment does not have non-Fermilab collaborators at this time.

3.1 Placeholder [$0k]

IV. RESPONSIBILITIES BY INSTITUTION - FERMILAB

4.1 Fermilab Accelerator Division

4.1.1 The experimenters require Accelerator Division support in approving of the use of the particular Tevatron magnet, allowing for use of the Laser lab in the Linac area, and allowing Ray Tomlin (6 weeks) and Xi Yang (2 weeks) to work/consult on the experiment.

4.1.2 The Accelerator division will provide use of the Continuum Surelite Laser as well as an HeNe alignment laser and other optical components under Ray Tomlin's care.

4.1.S Summary of Accelerator Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	8.0

4.2 Fermilab Particle Physics Division

4.2.1 The Particle Physics Division will be the source of M&S funds for the experiment. The costs include approximately $10K for PMT modules, $10K for mechanical hardware, $9K for optical components, and $1K for electronics for a total of $30K. In addition, a 50% contingency fund is to be made available after prompt notification to the division that such funds will be needed and such need is justified.

4.2.2 The PPD Mechanical team of John Korienek and Carl Lindenmeyer will be responsible for the design, fabrication, and installation of the laser box, PMT box, plunger, and interfaces between these items and the warm bore installed in the Tevatron magnet. Some of the pieces will require machine shop and welding workmanship.

4.2.3 The PPD Electrical Engineering Department will be responsible for providing engineering and technical support of the data acquisition system. This will include the use of QuarkNet board prototypes and modifications to these printed circuit boards. This effort will be led by Sten Hansen with technical assistance. The department will also provide support for software engineering by Al Baumbaugh who will write the graphical user interface and underlying software for the control of the experiment. Additional support will be provided for electrical parts of the safety system.

4.2.4 The PPD shall provide access to a Continuum Surelite Laser (currently under Hogan Nguyen's care) as a back-up to the accelerator division laser.

4.2.5 The PPD ES&H Department will assist in all of the necessary safety reviews.

4.2.6 The PPD will provide administrative support through the Experiment Physics Projects office.

4.2.S Summary of Particle Physics Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Mechanical design and fabrication			8.0 tech
Electrical engineering support			4.0 engineer
Machine shop fabrication			1.0 tech
Administrative Support			1.0
Mechanical pieces	$10K		
Optical components	$9K		
PMTs	$10K		
Electronics	$1K		
Total new items	$30K		14.0

4.3 Fermilab Technical Division

4.3.1 The Technical Division will be responsible for the operation of the Tevatron dipole magnet on the test stand at MTF. This includes the installation of the magnet onto the test stand and the connections to the feed and return cans for cryogenic operation. Technical Division personnel will operate and monitor the magnet. These activities will be considered as MFT Test Stand operations and will not be directly charged towards the **G**amme**V** effort. The Technical Division will make the space on Test Stand 6 available to the project for the duration of the effort. It is understood that there may be circumstances for which higher priority activities may take precedence over **G**amme**V** and the schedule and even the experiment's priority on Test Stand 6 may be adjusted in order to take into account these priorities.

4.3.2 The Technical Division will supply power and cryogens necessary for the operation of the magnet throughout the duration of the project.

4.3.3 The Technical Division will provide limited technical assistance to PPD personnel who have the responsibility for the installation of the experiment and interfacing it with the magnet. The experimenters estimate the total involvement of **G**amme**V** specific technical support to total 1 person week.

4.3.4 The TD ES&H Department will assist in all of the necessary safety reviews.

4.3.5 The Technical Division will provide a nominal 5T (5100 amps) field with normal stability controls in place and will provide current and other routine monitoring data to the experimenters. The Technical Division will provide 120 hours of magnetic field to the experimenters usually in continuous duration of 4-10+ hours although short interruptions and durations as short as 1-2 hours are acknowledged as being acceptable by the experimenters. Because of priorities, the Technical Division can choose these hours during weekend or swing shift times if necessary. The Technical Division will consider a possible request for additional hours beyond 120 hours within the context of this MOU in the event that the experimenters require further investigations of a possible signal.

4.3.S Summary of Technical Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	1.0

4.4 Fermilab Computing Division

4.4.1 The Computing Division will provide support for web space and a document database and similar support normally made available to experimenters. The experimenters will be responsible for maintaining the web space and document database.

4.4.2 The Computing Division will provide other support as needed including PREP with the understanding that the experimenters will follow the terms described below under Special Considerations for the prompt return of any required modules.

4.4.S Summary of Computing Division costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	0.2

4.5 Fermilab Workforce Development and Resources Section

4.5.1 The Workforce Development and Resources Section will provide use of QuarkNet data acquisition boards for use by the experiment. These will be returned to the Education Office after the project is completed.

4.5.S Summary of Workforce Development and Resources Section costs:

Type of Funds	Equipment	Operating	Personnel (person-weeks)
Total new items	$0.0K	$0K	0.0

4.6 Fermilab ES&H Section

4.6.1 The ES&H Section will provide assistance with safety reviews and safety approvals in order to help insure the experiment will be conducted in a safe manner.

V. SUMMARY OF COSTS

Source of Funds [$K]	Equipment	Operating	Personnel (person-weeks)
Particle Physics Division	$30K	$0.0K	14
Accelerator Division	0	0	8
Computing Division	0	0	0.2
Technical Division	0	0	1
Workplace Development Section	0	0	0
ES&H Section	0	0	0
Totals Fermilab	$30.0K	$0.0K	23.2
Totals Non-Fermilab	$0K		

VI. SPECIAL CONSIDERATIONS

6.1 The responsibilities of the GammeV Spokespersons and procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Experimenters" (PFX) (http://www.fnal.gov/directorate/documents/index.html). The Physicists in charge agree to those responsibilities and to follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ES&H) reviews are necessary. This includes creating a Partial Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The GammeV Spokespersons will follow those procedures in a timely manner, as well as any other requirements put forth by the division's safety officer.

6.3 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ES&H section.

6.4 All items in the Fermilab Policy on Computing
(http://computing.fnal.gov/cd/policy/cpolicy.pdf)
will be followed by experimenters.

6.5 The GammeV Spokespersons will undertake to insure that no PREP and computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Computing Division management. They also undertake to insure that no modifications of PREP equipment take place without the knowledge and consent of the Computing Division management.

6.6 Each institution will be responsible for maintaining and repairing both the electronics and the computing hardware supplied by them for the experiment. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

6.7 If the experiment brings to Fermilab on-line data acquisition or data communications equipment to be integrated with Fermilab owned equipment, early consultation with the Computing Division is advised.

6.8 At the completion of the experiment:

6.8.1 The GammeV Spokespersons are responsible for the return of all PREP equipment, Computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the GammeV Spokespersons will be required to furnish, in writing, an explanation for any non-return.

6.8.2 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ES&H requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters.

6.8.3 The experimenters will assist the Fermilab Divisions and Sections with the disposition of any articles left in the offices they occupied, including computer printout and magnetic tapes.

6.8.4 An experimenter will report on the test effort at a Fermilab All Experimenters Meeting.

SIGNATURES:

_____ / / 2007
Aaron Chou (co-PI), Fermilab

_____ / /2007
William Wester (co-PI), Fermilab

_____ / / 2007
Greg Bock, Particle Physics Division

_____ / / 2007
Roger Dixon, Accelerator Division

_____ / / 2007
Victoria White, Computing Division

_____ / / 2007
Victor Yarba, Technical Division

_____ / / 2007
Marjorie Bardeen, Workforce Development and Resources Section

_____ / / 2007
William Griffing, ES&H Section

_____ / /2007
Hugh Montgomery, Associate Director, Fermilab

_____ / /2007
Stephen Holmes, Associate Director, Fermilab

APPENDIX I - Hazard Identification Checklist

Items for which there is anticipated need have been checked

Cryogenics				Electrical Equipment				Hazardous/Toxic Materials	
X	Beam line magnets			X	Cryo/Electrical devices				List hazardous/toxic materials
	Analysis magnets				capacitor banks				planned for use in a beam line or experimental enclosure:
	Target			X	high voltage				
	Liquid Argon TPC				exposed equipment over 50 V				
Pressure Vessels				**Flammable Gases or Liquids**					
		inside diameter		Type:					
		operating pressure		Flow rate:					
		window material		Capacity:					
		window thickness		**Radioactive Sources**					
Vacuum Vessels					permanent installation			**Target Materials**	
1 ½" - 2"		inside diameter			temporary use				Beryllium (Be)
Atm–10-8 torr		operating pressure		Type:					Lithium (Li)
Glass BK7		window material		Strength:					Mercury (Hg)
3/8" + 1/2"		window thickness		**Hazardous Chemicals**					Lead (Pb)
Lasers					Cyanide plating materials				Tungsten (W)
	Permanent installation				Scintillation Oil				Uranium (U)
X	Temporary installation				PCBs				Other :
	Calibration				Methane			**Mechanical Structures**	
X	Alignment				TMAE			X	Lifting devices
Type:		Continuum Surelite Nd:Yag			TEA				Motion controllers
Wattage:		9W, 420mJ/5ns @ 20 Hz			photographic developers				scaffolding/elevated platforms
class:		IV			Other:				Others

APPENDIX II Laser Hazard Requirements

All personnel on the project who deal with the laser will be required to go through safety training suitable for the Class IV status of the laser.

Further information from Ray Tomlin follows:
The people that oversee safety in Accelerator Division laser labs are listed here.
Ray Lewis, Mike Bonkalski. Also, Tim Miller has a nice web page:
http://www-esh.fnal.gov:8001/Laser_Safety/Laser_Safety_files/frame.htm

Lab laser safety guidelines are here:
http://www-esh.fnal.gov:8001/Laser_Safety/Laser_Safety_files/frame.htm

Ray Tomlin operates the LINAC laser labs in AD and has been even more conservative than the ES&H folks striving for zero exposure if possible.
Rich Ruthe (TD, SSO) has attended the class 4 laser committee meetings sponsored by Tim Miller so he has had at least indirect input on the operation of this laser and all the class 4 lasers on site.

The laser to be used for the **G**amme**V** experiment is a Continuum SureLite I-20. It fires a 420 milli joule, 5nsec pulse at 20 Hz. Wave length is 1064 nm, in the near IR, and invisible. Average power is 9 to 10 watts of photons. The laser outputs 160 mJ at 20 Hz when frequency doubled to 532nm.

This laser has been in two laser labs run by Ray Tomlin. It has been in service in the pre-accelerator. While in the pre-accelerator, it was enclosed in a metal box. Passers-by could reach out and touch the box. The box was light tight and covers were interlocked. Since the IR beam was fired into the H- beam line, interlocks included vacuum valve status, vacuum level status, PREAC HV status, in addition to the microswitches on the laser box covers.

APPENDIX III Cryogenic and Electronics Hazard Requirements

The **G**amme**V** will use cryogens (liquid N_2 and He) as they are used for magnet operations by the Magnet Test Facility within the Technical Division. TD specified safety procedures will be followed. The electronics equipment is modest with no exposed high voltages. Circuitry will be appropriately fused and protected as required by safety concerns.

APPENDIX IV RUN PLAN.

1)	Rigging, installation, setup	May 1 – June 1, 2007
2)	Alignment and Calibration at MFT	June 1 - June 15, 2007
3)	PMT tube commissioning	June 15 – June 22, 2007
4)	Data taking	June 22 - July 15, 2007
5)	Optional running time if needed	July 15 – July 31, 2007